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HYDROGEOLOGICAL ASPECTS OF GROUNDWATER HAZARD IN POLISH UNDERGROUND MINING

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ABSTRACT

The characteristic hydrogeological features of the most important mineral deposits mined in Poland are specified and the classification of groundwater hazard sources met in Polish underground mining is presented. A review of different methods aiming at the exploration of potential sources of groundwater hazard is given and the outlines of both the defensive and offensive strategies of fighting groundwater hazard are pointed at.

HYDROGEOLOGICAL FEATURES OF MINERAL DEPOSITS MINED IN POLAND

A number of different minerals are mined in Poland. To the most important belong: hard coal, lignite, copper ores, zinc-lead ores, native sulphur, rock salt. The others, for example sedimentary iron ores are of minor importance.

Along with minerals large volume of groundwater, estimated at about 1,2 km^3 is withdrawn from the mines each year. It represents ca 10% of the total demand on water by the national economy and population. The volume of groundwater pumped by different branches of the mining industry is given in Table 1.

The mineral deposits occur in very diverse hydrogeological conditions. Hard coal occurs in three basins: the largest is the Upper Silesian /GZW/, the smallest the Lower Silesian /DZW/ and the Lublin Coal Basin /LZW/, beeing actually developed. All of them are of Upper Carboniferous age. The mined coal seams are up to a few meters thick and occur within the series of watertight claystones or mudstones, and acting as aquifers sandstones or conglomerates.

From the point of view of potential water danger among others the presence of overburden and its lithology is very important. In the DZW the Carboniferous usually crops out at the surface, and the overburden does not play any important hydrogeological role.

As far as the strata overlying the Carboniferous in GZW are concerned this basin can generally be devided into three zones. The northern covered with waterbearing carbonate Triassic, the central one where Carboniferous is overlaid with alluvial and fluvioglacial sands and the southern one where overburden consists mainly of Tertiary marine, impermeable clays. Their thickness reaches up to some hundred meters.

Branch of mining industry	Volume of water pumped 10^3 m^3 /day	Proportion of the total volume of water pumped by the mining industry
Hard coal mines	1095	35.4
Lignite open pit mines	1052	33.9
Zinc and lead ore mines	487	15.8
Stowing sand open pit mines	244	7.9
Copper ore mines	118	3.8
Chemical raw materials mines, partly /native sulphur/ open pit mines	50	1.6
Common mineral raw materials open pit mines	50	1.6

Table 1. Volume of groundwater pumped by different branches of the mining industry in Poland

The combination of the lithology of the Carboniferous and of the overburden together with intensive disjunctive tectonics and mining factors, such as size and depth of the mines, their age, rate of production, systems of mining etc. cause that the normal water inflow to the mines in the GZW varies from ca 2 to ca 40 m^3/min.

The characteristic hydrogeological feature of the Lublin Coal Basin /LZW/ is the great thickness of the overburden that amounts to about 700 m. It is built up of the Cretaceous and the Jurassic. The latter /fissured limestones/ together with the lowest portion of the Cretaceous /swimming sand/ represent an aquifer which in the future may endanger the exploitation of coal seams. It caused recently the flooding of a shaft that was beeing sunk. Extensive studies are under way aiming at the search of the optimal method of draining this aquifer.

The big sedimentary copper deposit of Upper Permian age /Lower Zechstein/ is connected with the Fore-Sudetic Monocline. Within the sedimentary series from 400 m to 1000 m thick overlying the copper bearing shale two complexes of waterbearing sediments occur. The upper one, ca 300 - 400 m thick consists of Quaternary and Tertiary sands and gravels of continental origin. The lower complex is represented by fissured Lower Zechstein limestones and dolomites. They are the source of water inflows to the mines and are fed with water at the outcrops which are situated immediately under the Tertiary cover. The rate of water inflow to the existing mines varies from 2 to 12 m^3/min.

The Tertiary lignite and native sulphur are mined by open cast system, and sulphur in addition by underground melting. Therefore they will not be discussed in this paper.

Zinc and lead ores occur along the northern rim of the Upper Silesian Coal Basin, within a series of extremely permeable karst fissured Middle Triasic limestones and dolostones. The deposits lie at little depth and usually the Triassic aquifer is covered only with fluvioglacial sands. The last ones often fill buried river valleys. The main ways of groundwater circulation are fissures, joints and karst channels. They are recharged directly with meteoric waters and surface streams. The mines pump between 40 and 250 m^3/min. of water, what is a record volume not only in Polish mining.

Rock salt deposits are either of Permian /Northern and Central Poland/ or of Miocene age. The last ones are situated in Southern Poland within the Carpathian Foredeep. The Permian deposits are the result of halokinesis, and have the shape of salt domes. They are surrounded with waterbearing Mesosoic strata and covered with a gypsum cap which usually acts as a groundwater reservoir. In 1977 for the first time in the history of Polish mining one of the salt mines had to be abandoned and was totally flooded by waters originating from a gypsum cap.

The Miocene salt deposits occur in more favorable hydrogeological conditions within a series of generally impermeable marine clays. However, the unique, world known, ancient salt mine in Wieliczka in operation for over eight centuries, was several times endangered by sudden brine of fresh water inrushes. They came either from the Quaternary overburden or the Tertiary surrounding rocks. At present extensive studies are in progress aiming at the determination of the most effective way of liquidating the salt water entrance, which since 1973 has been slowly leaching the protecting border pillar of the mine, thus creating a serious water hazard to it.

Sedimentary sideritic iron ores of Middle Jurassic age are connected with the Cracow-Silesian Monocline. They occur in the bottom of a clayey series and are immediately underlaid with and affluent aquifer built up of weak sandstones and sands. The last cause a great water problem for the underground mining. Groundwater inflow to the mines varied from 10 to 35 m^3/min. The last iron-ore mines have been recently abandoned.

SOURCES AND CATEGORIES OF GROUNDWATER HAZARD

Besides of the "normal" water inflows to the mines one sometimes has to do with sudden, more or less unexpected inflows or even inrushes of underground or surface waters and waters with suspensed solid material. The possibility of such inrushes which may endanger mine workings and crew is defined as "water hazard". With this term the concept of "the source of water hazard" is strictly connected.

We distinguish two classes of water hazard sources: 1 - characterized by unlimited freedom of water movement, 2 - characterized by limited freedom of water movement. To the first class there belong: a/ surface streams and water reservoirs, b/ abandoned water logged mine workings, c/ karst caves, channels, etc., d/ open fault zones. To the second class there belong: a/ water-bearing consolidated host and surrounding rocks, b/ water bearing consolidated overburden strata, c/ tight fault zones, d/ unproperly sealed off old bore-holes.

As an example, there are given below the data illustrating the sources of 225 water inrushes to the Upper Silesian coal mines, which took place during the period of 25 years: fault zones - 30%, waterbearing Carboniferous strata - 27%, waterbearing overburden - 22%, old flooded mine workings - 18%, surface streams and water reservoris - 2%, old surface boreholes - 1%. The distribution of the inrush debit was the following: less than 1 m^3/min - 33%, between 1 and 3 m^3/min - 25%, between 3 and 5 m^3/min - 12%, more than 5 m^3/min - 30%. Among the last, there were a few which brought catastrophic results.

The evaluation of mine water hazard is a very complex problem since the hydrogeological and mining situation which decides on the possibility and on the debit of a sudden water inflow varies in space as well as with time.

According to the Polish mining safety rules all underground mines or their portions are classed among one of the three categories of water hazard.

To the first category there belong underground mines or their portions, if:

1/ water reservoirs and surface streams, waterbearing porous and karst-fissured strata are isolated from mine workings with an unprevious rock series and the existing and planned mine workings will not cause the lose of isolating properties of that series;

2/ porous aquifer occuring within the deposit or its immediate surrounding is isolated from mine working with impermeable rocks of adequate thickness and mechanical properties;

3/ the "static" (not renovable) water reserves of the waterbearing rocks have been drained out and water inflow to mine workings can originate only from the "dynamic" (renovable) water resources;

4/ there occur other sources of water hazard classed to the second category, if they cannot cause water danger for more than a single mine working.

The second category of water hazard comprises the following situations:

1/ surface water reservoirs and streams or underground water-logged mine workings can indirectly /on the way of filtration/ cause water inflow to the mine workings; or

2/ in the hanging wall or in the bottom of the deposit there occurs a porous groundwater horizon not isolated with and adequately thick and strong, isolating layer, or

3/ there occurs waterbearing fissured or karst-fissured water horizon isolated from the mine workings with a watertight layer adequately thick and strong, or

4/ there occur waterbearing faults sufficently explored as far as their water capacity and location is concerned, or

5/ there occur bore-holes drilled from surface, not properly sealed off or there exists no information as to the mode of their liquidation, if the bore-holes create the possibility of direct hydraulic contacts between mine workings and surface-or underground water reservoirs, or

6/ there exist water hazard sources classed to the third category, if they cannot cause water danger for more than a few mine workings.

To the third category of water hazard there belong underground mines or their portions if:

1/ surface water reservoirs or streams create the possibility of direct inrush of water to mine workings,

2/ in the immediate roof or bottom of the deposit there occurs a waterbearing fissured or karst-fissured horizon,

3/ within the mineral deposit or immediately above it there occur water reservoirs,

4/ immediately below the mineral deposit there occur water reservoirs under hydrostatic pressure,

5/ there occur waterbearing faults which have not been explored from the viewpoint of their hydrogeological properties and location,

6/ there exists the possibility of an inrush of water or water with suspensed solid material to mine workings, providing that one of the mentioned water hazard sources can endanger the mine as a whole or its considerable portion.

The water hazard categories for rock-salt mining are defined in a different manner.

In mines and their zones classed to different water hazard categories the mining operations have to be carried out according to specific and detailed principles and rules.

METHODS OF EXPLORATION OF POTENTIAL SOURCES OF GROUNDWATER HAZARD

The proper evaluation of water hazard depends in the first place on a satisfactory exploration of the hydrogeological, geomechanical and mining conditions. Only a thorough exploration makes possible the identification of the sources of water hazard, the application of preventive and protection measures while carrying out mining operations and the planing of the liquidation of water hazard sources and its execution.

The hydrogeological exploration of water hazard sources is in Polish mining carried out in two phases: the preliminary and the detailed one. The preliminary phase takes place before the deposit is opened and developed and bases chiefly on surface bore-holes and geophysical investigations. The results are presented in a special report /"documentation"/. They give insight into the general hydrogeological conditions of the mineral deposit and indicate the endangered zones which further on shall be explored in details.

In the phase of detailed investigations the adequate knowledge of the hydrogeological and geomechanical parameters, as well as the knowledge of the exact position and characteristics of the source of hazard should be achieved in order to plan the best way of handling it.

These studies should allow to collect the maximum number of information on technical and practical aspects of possible protective measures, within the context of the relevant geological processes and of the action of the miner himself.

The hydrogeological exploratory workings are carried out in advance of the opening and preparatory mine workings which are driven in the water endangered zones.

For the exploration of groundwater hazard sources the following methods in Polish mining are applied: a/ mining methods, b/ modelling methods, c/ geophysical methods, d/ radiometric methods, e/ hydrochemical methods, f/ geomechanical methods. Some of them are applied "in situ", the others in latoratories.

The mining methods are limited mainly to bore holes drilled either from surface or from underground mine workings in the direction of the water hazard source. They enable the estimation of hydrogeological and geomechanical parameters of the rocks, the position of the water table, direction and velocity of groundwater movement, hydraulic contacts between aquifers and mine workings, continuity and thickness of impermeable layers, presence of fissures, joints, karst channels, caves, old mine workings, etc. The boreholes are used for geophysical and radiometric measurements, for "in situ" measuring of the properties of rocks, and as draining and piezometric wells.

The methods of modelling /hydraulic, electrical, numerical/ are applied for prediction mine water inflows and replenishment of piezometric depression as function of time.

The geophysical methods which are more and more often applied and enable to recognize the location of rock-discontinuities, tectonic disturbances and empty or water filled spaces within the rockmassif.

Radiometric and hydrochemical methods are applied in order to identify sources and circulation ways of water appearing in mining workings, hydraulic contacts, water velocity, etc. The measurements of stabile /environmental/ as well as of artificial isotopes were several times applied with great success. The same refers to other kinds of groundwater tracers.

For the characteristics of hydrogeological aspects of water hazard the investigations into the mechanical and collectory properties of rocks are indispensable. They create the basis for the estimation of the extreme hydraulic gradients and groundwater velocities, the design of water safety pillar parameters, the safe lengths of exploratory and draining underground bore-holes, etc. Here belong also measurements of fissures and joints, their density, geometry, spatial orientation, etc.

Ussually, the detailed investigations include different methods and only a complex interpretation of their results renders it possible to draw final conclusions and under-take operative decisions regarding the prevention against and liquidation of water hazard.

PRECAUTION AND PREVENTIVE MEASURES AGAINST GROUNDWATER HAZARD

To the precaution and preventive measures there belong the following:

1. The strict observation of mining safety regulations, instructions, etc. Here belongs also the adequate activity of the mining hydrogeologists obligatory employed in each underground mine coping with groundwater problems. The field of compentence and responsibility of these specialists is very broad. The general water hazard situation of each mine is periodically discussed at the session of Water Hazard Commissions which act a three levels: at the mine, at the mining company headquarters and at the level of the chief of the mining branch /coal mining, nonferrous metals mining, chemical raw materials mining, etc./.

2. The steady readiness of main water draining and pumping system to intercept any additional volume of water.

3. Isolating of endangered mining workings from the rest of the mine with adequate water safety-or filtrating-dams.

4. Designing and leaving of protective pillars and protective layers between mine workings and the sources of water hazard.

5. Application of exploitation systems protecting impermeable layers in hanging walls /e.g. compact stowing/.

6. Strengthening of mine working lining in the tectonically engaged zones, and other zones where rocks with low geomechanical parameters and suspected as waterbearing occur.

7. Application of injections through bore-holes in order to seal off and strengthen the rock formations.

8. Preparation of adequate rescue action for the case of water inrush.

The above mentioned measures can be classed as preventive and passive means of protection against water hazard. They aim to prevent or delay water inflows or to reduce their intensity, to evacuate the water that has infiltrated the mine by pumping or by water tight separation of the flooded area, or again by sealing off the fractures through which the water has entered.

On the basis of this passive protection, it is aimed to plan mining works with a predetermied safety level, which directly affects the preparation costs. As a matter of fact, the essence of the philosophy of the passive, defensive strategy is the adjustement to the existing hydrogeological conditions. In the opposite the offensive, active protection is based on the attempt to radically change these conditions and to liquidate the sources of water hazard. It requires the removal of surface reservoirs or streams and draining of old water logged workings, waterbearing strata, fractured tectonic zones, karst channels, caves, etc. Sometimes the reduction of the water pressure is sufficient. The draining or water head lowering is achieved ussually by means of bore-holes drilled either from the surface or from underground.

In Polish underground mining, in relation to local conditions, both strategies of fighting water hazard are employed, often combined with each other.

In certain conditions the draining of waterbearing horizons can be achieved only on the way of driving special water draining galeries beneath the mineral deposit and exploitation workings. An example of such a situation represents the before mentioned zinc-lead ore mining, and sedimentary sideritic iron ore mining. The reduction of piezometric head is a standard procedure and safety requirement in copper ore mining in the Fore Sudetic monocline. The same refers to some portions of coal mines in Upper Silesia, where mined coal seams crop out directly under the waterbearing Triassic or under deep Preplejstocene or Plejstocne buried river valleys filled with fluvioglacial sands.

To introduce both the defensive and offensive strategy of fighting against water Polish mining has developed an advanced technology, which is adjusted to the particular circumstances of each specific case.

Closing these remarks it should be pointed at the fact, that although the offensive strategy is likely to solve radically the water hazard problems it often also has a considerable and quite long lasting effect on the hydrogeological balance of the whole region. Thus the fight against water hazard in mining becomes sometimes a part of the problem of environmental protection, and water supply. Therefore at present all water problems in most of the mining districts in Poland, especially in Upper Silesia, are regarded as dealing with one water system, and efforts are undertaken to solve them using adequate scientific methods.